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Studies on the productivity of Pos'et Bay (Sea of Japan) in relation to the problems of recovery of stocks of yezo scallop (Mizuhopecten yessoensis)

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Studies on the productivity of Pos'et Bay (Sea of Japan) in relation to the problems of recovery of stocks of Yezo scallop (Mizuhopecten yessoensis)

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by

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Introduction

Irrational exploitation of natural stocks of commercial invertebrates in the coastal zone of the Sea of Japan has led to a significant decrease in the numbers of many species. For example, the stocks of the important commercial species of scallop, Mizuhopecten yessoensis, in the Gulf of Peter the Great have decreased to almost one-third in the past 40 years (Biryulina and Rodionov, 1972). As a result, the prohibition of commercial exploitation

* The figures in the right-hand margin indicate page numbers of the original (Tr.)

of most species was accompanied by an intensification of scientific studies aimed at the development of theoretical principles governing the reproduction of commercial species. In 1970 an experimental marine resource management unit (OPMKh) was established at Pos'et settlement (Southern Maritime Region), whose task it was to initiate wide-ranging attempts to restore the weakened populations of bottom-dwelling invertebrates. The planning of the long-term program of studies on the reproductin of the scallop, Mizuhopecten yessoensis required at first the solution of several problems. These were, first - to determine the suitability of different regions of Pos'et Bay for the cultivation of mollusks, second - to evaluate the effects of the main environmental factors on the rate of growth of scallops (in particular to determine the temperature at which growth occurs) and third - to determine the optimal density of planting in suspended enclosures for the rearing of this year's brood of M. yessoensis. This communication 167/ deals with the solution of these problems.

Materials and Methods

Most of the research was conducted between May 1971 and October 1972. Five typical sites, far removed from each other, were chosen as standard biotopes: four coastal sites (stations Nos. 1, 2, 3, 5 located respectively in Novgorodskaya, Ekspeditsii, Minonosok and Khalovei coves) and one site in the open part of the gulf (station No. 4 in Zapadnaya cove of Furugel'm Island), at depths of 7-10 metres and 16-18 metres respectively (Fig. 1).

A scallop population was present at each of these stations. Series of long-term observations were conducted in order to solve these problems.

1. Changes in the salinity, concentration of dissolved oxygen, and temperature were followed at 4-5 levels at all stations.

2. The level of primary productivity, as a measure of availability of food, was determined according to the pigment content of phytoplankton and the amount of seston. These determinations were made according to well-known methods (Report of Scor-Unesco Working Group 17, 1966; Ostapenya, 1968).

3. Observations were made on the rate of growth of brood obtained from collectors, at all the levels at station No. 2, following initial planting of 80, 160, 400, 800 and 1600 specimens per square metre of the base of the suspended enclosure. The rate of growth of the experimental scallops was taken as one of the indices of productivity at station No. 2; 168/ these data were used to calculate the production of flesh during the first year of life.

4. The size-age structure of the investigated M. yessoensis populations was studied with the use of the method of Petersen and the probability paper analysis (Cassie, 1954; Bregman, 1971). The size-age structure was used to determine the rates and variations of growth of individual specimens, and the numerical relationships between age groups. These data, together with the previously obtained data on the numbers of scallops, were used to calculate the productivity of populations by means of well-known methods (Vinberg, 1968).

5. Organic matter content in the bottom soil of the stations was determined.

6. The species composition of the bottom populations of the biotopes was studied. In a previous study (August 1969 - October 1970) growth of 53 species of scallops from a 25 square metre bottom enclosure in Troitsa cove (station No. 6) was followed in relation to seasonal temperature changes.

In the course of data processing the growth rates of experimental and control scallops were compared. In the case of the latter the growth data were obtained through the analysis of the size-age structure of the population. In conclusion, a comparison was made, with the aid of an electronic computer, between the changes in the linear measurements of scallops from the suspended enclosures at the half-way level of station No. 3, and 169/ changes in the indices of productivity and those in the physico-chemical conditions. Specifically, the problem was stated as follows:

1. Evaluation of the possibility to predict changes in the rate of linear growth of scallops, based on the above-mentioned factors;

2. Identification of environmental factors most closely related to changes in linear size of the body of M. yessoensis. This was done with the use of the multiple linear regression method, in which the predictors were the envronmental factors and the dependent variables were the lengths of shells. This program was developed at the

Institute of Automation and Control Systems at the Far Eastern Science Centre of the Academy of Sciences of USSR, and performed on the "Minsk-22" electronic computer.

Results

I. A brief characterization of the physico-chemical environmental conditions, bottom soils and biocenoses of the stations under study.

As mentioned above, stations Nos. 1, 2, 3 and 5 were generally located in closed bays of the gulf, while the deep-water station No. 4 was in open coastal waters. Thus, the physico-chemical conditions at the "coastal" biotopes were less stable, and to a greater extent subject to the effects of atmospheric precipitates and wind agitation.

The animal life at these bottom biotopes was represented by a fairly wide range of species (listed below in consecutively decreasing numerosity): Patiria peotinifera, Stichopus japonicus, Strongylo-centrotus intermedius, Mizuhopecten yessoensis, Halocynthia sp. sp. Distolasterias nipon, Asterias amurensis. The cold-water scallop, Swiqdopecten swifti, was found only at station No. 4, and the thermophilic mollusks, Arca boucardi and Chalamys nipponensis, at station No. 1. The numbers and the biomass of the scallop M. yessoensis at the stations studied varied between 7 and 109 specimens, and 2.2 and 64.4 kg per 1000 square metres of surface. Organic matter content fluctuated between 1.6 and 13.7%. It is of interest that the number of scallops was inversely proportional to the amount of organic matter. With mean organic

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matter concentrations higher than 8% the number of mollusks was seen to decrease.

This relationship presupposes that at shallow stations there occurs a roiling of sediments and that the resulting suspension blocks the filtration apparatus of the mollusks. This was noted earlier by Yamamoto (1964). In addition, the intensive oxidation processes taking place in the silt probably result in oxygen deficit in the deepest layers of water. These factors must limit the number of scallops.

II. Size-age structure of populations; rates of individual growth, and effect of temperature.

The size-age structure of populations (Fig. 2), as determined by the modal dimensions of the body, variation of individual sizes within the limits of increment of groups, and the number of groups were found to correspond to literature data (Bazikalova, 1934; Colicov and Scorlato, 1970; Biryulina and Rodionov, 1972). The similariity of the rates of linear growth of scallops in different locations of Pos'et Bay was corroborated. However, in the open part of the bay (station No. 4, Zapadnaya) the scallops grew somewhat faster and reached a mean length of 16 cm by their eighth year, while in other places, only that of 15.4-15.6 cm (Fig. 3). Growth of M. yessoensis mainly took place at temperatures between 0 and 18 degrees C, and became retarded at higher temperatures. The optimal temperature range was about 10-12 deg. C (Fig. 4). At moderate depths the scallops grew mainly in the autumn

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and in the spring, and at the deep-water station No. 4, also in the summer, as the highest water temperature there near the bottom did not go above 17 degrees C. In general, the scallop population at station No. 4, unlike other populations, was represented by mainly older age groups with shell sizes of up to 22 cm. In addition to a somewhat increased rate of growth this can be explained by an extended period of no commercial fishing and by more favourable conditions for natural survival (stability of temperature and salinity, increased oxygen concentration, etc.).

III. A.Characterization of the level of productivity of waters in Pos'et Bay; concentration of planktonic pigments (chlorophylls "a", "b" and "c" and carotinoids).

Results of studies on the determination of 172/ concentrations of planktonic pigments were as follows:

1. The stations chosen for the determination of planktonic pigments were moderately productive. Amounts of chlorophyll "a" in them fluctuated, as shown below:

Minonosok cove 0.02-14,92 mg/m^3 (Tr. given as Kg?) and 0.19-97.22 mg/m^2;

Novgorodskaya cove 0.13-1.19 mg/m^3 and 0.92-7.46 mg/m^2;

Khalovei cove 0.01-1.42 mg/m^3 and 0.40-6.55 mg/m^2;

Furugel'm cove 0.04-0.68 mg/m^3 and 1.39-8.11 mg/m^2;

Ekspeditsii cove 0.08-9.80 mg/m^3 and 1.07-36.61 mg/m^2.

(Fig. 5).

2. Chlorophyll "a" concentration varied considerably at all stations during the observation period. The highest concentrations (per m^3) were observed in the winter time (especially in Minonosok cove), and the lowest - in the month of April; productivity was somewhat higher in the autumn than in the summer, but statistically significant differences between these seasons were noted only in Minonosok cove (actual = 33.3; table values 5.12 and 10.56 at P = 0.05 and P = 0.01 respectively). On Furugel'm Island there were also significant differences between summer and autumn, but only in a column of water under 1 square metre of surface and only at a significance level of 0.05 (actual = 7.29; table value = 5.99).

3. At all stations, with the exception of Furugel'm Island, vertical distribution of chlorophyll "a" was generally uniform, with a slight increase at benthic levels. There were no statistically significant differences. At the Furugel'm Island station the differences between the concentrations in surface layers of water and the higher concentrations at the benthic layer were statistically significant. 173/

4. Comparison of stations (in the summer and autumn, since this is when most of the parallel observations were made) has shown that, according to chlorophyll "a" concentration per unit volume (m^3), the most productive station, both in the summer and autumn, was the one in Novgorodskaya cove; Minonosok and Khalovei coves were close to each other, and their productivity (according to chlorophyll "a")

was somewhat lower than at the Novgorodskaya cove station. Waters near Furugel'm Island were found to be the poorest in productivity. However, the differences between the data for all the stations were not statistically significant.

5. The highest chlorophyll "a" concentration in a column of water with a surface area of 1 m^2 was found at Furugel'm Island, followed by Novgorodskaya, Khalovei and Minonosok coves but the differences were not great and not statistically significant.

6. The differences between the stations according to total pigments were the same as those according to chlorophyll "a".

B. Seston content.

The regions studied were moderately productive in seston content, as in pigment concentration. During the period of observation, which included four seasons, the fluctuations at all stations were not very significant (Fig. 6), unlike the pigment composition of the phytoplankton (0.5 to 9.0 kilocalories per m^3).** There was no synchrony in seasonal changes. At all stations the vertical distribution 174/ of seston at different depths was uneven, but these changes were not regular. The differences between the different levels were not statistically significant.

A comparison of the four stations has shown that in seston content per 1 m^3 **, Khalovei cove was the richest, followed by Novgorodskaya and Minonosok coves (very close to each other), and the poorest were the waters at Furugel'm Island. However, these differences, as those in pigment

** In the original it is given as m/. It is assumed to be a misprint. Tr.

concentration, were not statistically significant (actual = 0.03; table values = 2.82 and 4.30 at P = 0.05 and P = 0.01 respectively.

IV. Productivity of Mizuhopecten yessoensis populations.

Population productivity was calculated as the total increase of raw tissue substance of all the individuals constituting a given population during 1 year per 1 m^2 surface of the bottom. The results of the calculation (Table 1) led to the following conclusions:

1. Because of the similar size-age structure and similar rates of growth, the values of unit productivity and of P/B coefficients (P = productivity, B = biomass) for most populations studied were found to be the same. The elevated value of the P/B coefficient at station No. 1 can be explained by a predominance there of young scallops.

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2. On the whole, the most productive M. yessoensis population was found at station No. 4, due to the higher rates of growth of adult individuals, combined with the increased numbers of scallops. The least productive populations were found at stations Nos. 1 and 2.

Table 1. Productivity of stations

Time of recording	Station numbers	P, g/m^2	B, g/m^2	P/B per year
1972.	I	0,25	0,44	0,57
1971.	2	0,20	0,80	0,26
July 1972.	3	I,I8	4,95	0,24
August 1972	4	3,20	I2,I9	0,26
1972	5	1,00	4,30	0,23

V. Growth and productivity of this year's brood of M. yessoensis in suspended enclosures.

The following patterns were established following observations on the growth of experimental scallops:

1. The scallops grew at the same rate at different levels of station No. 3.

2. With an increase of initial density of planting from 80 to 1600 specimens per square metre, the relative rates of linear growth decreased correspondingly from 0.97 - 1.01 to 0.58 - 0.59, i.e. 1.7 times (Fig. 7).

3. Mortality of scallops in enclosures during 176/
a 1-year period, following planting of 80-800 specimens per square metre was only 2.5 - 5% (occasional increased mortality was due to incidental causes); an increase of planting density to 1600 specimens per square metre was accompanied by a notable increase in mortality (up to 16 -20%).

4. Although individual growth rates were higher with low densities of planting, the total absolute values of productivity were the greatest at the initial planting density of 800 specimens per square metre, while the values of unit productivity were generally the same at all levels following planting 80 - 400 specimens per square metre (Table 2).

In total, 37 Kg of meat was obtained during one year from 1 square metre of surface water. If there were not any gaps between groups in the five enclosures, then, because each group occupies approximately .75 m of vertical space, and the station itself is 8 m in depth, the productivity could reach about 130 Kg. If it is assumed

that the same high planting density of 800 specimens per square metre were to be applied in all the enclosures, and given that the mollusks in each enclosure filter only that layer of water in direct contact with the enclosures, then the annual scallop production could represent approximately 180 Kg of meat per square metre of water surface. This figure gives an idea to a certain extent of potentially possible scallop production in enclosures during the first year. It can be seen from Table 4 that the values of unit productivity (P/B) remained practically at the same level when the planting density was increased from 80 to 200 specimens per square metre. When the planting density 178/ was increased 10-fold (from 80 to 800 specimens per square metre) the P/B coefficient became decreased by only 6-18 %. A further increase of planting density (up to 1600 specimens per square metre) was accompanied by a 28-30% decrease in productivity, as compared to that following planting density of 80 specimens per square metre.

Thus, with a good survival rate and considering efficient management, it may be concluded that planting density of 800 speciment per square metre would be quite tolerable, and probably nearly optimal, for growing this year's brood of M. yessoensis in suspended enclosures under conditions prevailing in Minonosok cove and others similar to it.

Table 2. Productivity of mollusks grown in enclosures

Level (depth) in m	Enclosure number	Number of specimens per square metre and biomass of raw substance in Kg/m²				% mortality	P for 1 year, Kg/m²	B in Kg/m²	PB
		at the beginning		one year later					
					B				
2,5	I	80	0,069	64	I,07	20,0	I,0	0,57	I,75
	2	200	0,I4I	I73	2,I2	I3,0	I,98	I,I30	I,75
	3	400	0,248	390	3,25	2,5	3,0I2	I,750	I,72
	4	800	0,424	82I	4,50	0	4,076	2,462	I,65
	5	I60C	0,848	I277	3,9I	20,2	3,062	2,380	I,29
4,5	I	8C	0,065	78	I,347	2,5	I,282	0,705	I,82
	2	200	0,I24	200	2,224	0	2,I00	I,I74	I,79
	3	400	0,248	366	3,040	8,5	2,792	I,644	I,70
	4	800	0,424	8I0	4,098	0	3,874	2,25I	I,62
	5	I600	0,848	I344	4,088	I6,0	3,240	2,468	I,3I
6,5	I	80	0,064	76	I,286	5,0	I,222	0,670	I,83
	2	200	0,II7	206	2,234	0	2,II7	I,I75	I,80
	3	400	0,22I	384	2,944	4,0	2,723	I,582	I,72
	4	800	0,424	642	3,0II	I9,7	2,587	I,7I7	I,5I
	5	I600	0,848	998	3,005	37,6	2,I57	I,926	I,I2

VI. Effects of the main environmental factors on the growth of scallops in suspended enclosures.

As mentioned above, the data on the growth of scallops at the mid-depth level at station No. 3, after an initial planting of 80 specimens per square metre, were correlated with seasonal fluctuations of temperature, salinity, oxygen content and the level of primary productivity.

The results of correlation analysis are presented in Table 3. The figures in the second column show to what extent changes in "X"-factors affect the value of "y". A combined effect of all five factors determined the change of "y" by 94%, that of four (without X_2) - by 93%, of three (without X_1& X_2) by 91.7%, of two (without X_1,X_2 & X_4) by 0%; factor X_5 (oxygen content) caused the change of "y" by 88.5%.

It must be noted that the combined effect of 179/ the factors was significant, since the Fisher test values (F) were higher than those in the table, at levels of significance generally not lower than P = 0.01.

Table 3. Results of analysis of correlation between changes in linear body size and environmental factors

Factors	Correlation	Significance	Significance of factors	
I	2	3	4	5
X_I-X_5	0,9396	55,955	X_2 = S	3,254
X_I,X_3,-X_5	0,9286	6I,800	X_I = P	3,2I5
X_3-X_5	0,9I66	73,224	X_4=	3,983
X_3, X_5	0,8998	94,429	X_3 =	3,I62
X_5	0,8849	I69,072	X_5 = O	I69,072

$y \cdot X_5 = 0,94I$

Legend: X_1 (=P) - pigments; X_2 (=S) - seston;
X_3 (=t) - temperature; X_4 (=s) - salinity;
X_5 (=O) - oxygen; $y \cdot X_5$ - coefficient of correlation of y according to X_5.

Thus, growth rates of scallops were least correlated with seston and photoplankton pigment content, and most correlated with the concentration of dissolved oxygen. It seems to us that the former can be explained by a lack of specificity of food requirements, since there was sufficient food available even during periods of lowest phytoplankton growth; phytoplankton could be substituted by bacteria which account for a significant proportion of primary 180/ productivity in Pos'et Bay (Karapetyan, 1971). The latter, i.e. the effect of oxygen concentration can be explained by the fact that during scallop growth period, when the water temperature was the lowest and oxygen concentration was high, the mollusks grew well, but later, at lower oxygen concentrations, in spite of higher temperatures, scallop growth was retarded.

Conclusions.

1. Scallops, M. yessoensis, obtained from collectors during the first year of their life, must be maintained in the pelagic zone, but later may be transferred to open bottom soil.

2. The nearly optimal population density is about 800 specimens per square metre of suspended enclosure.

3. General requirements of sites used for growing scallops are: a) moderate temperature conditions (maximal

water temperature not higher than 18 degrees C, and optimal range between 10 and 12 degrees C; b) sufficient concentration of dissolved oxygen (not less than 6 ml/l); c) minimal concentration of suspended silt particles. Soil at bottom sites should not contain more than 8% of organic matter. In Pos'et Bay the sites most closely conforming to these requirements are the open/deep-water regions near Furugel'm Island, and least conforming ones are the Novgorodskaya and Ekspeditsii Bays.

4. Pos'et Bay waters were found to be moderately productive. Differences between the primary productivities of its different regions were not statistically significant.

5. The size-age structures of the 181/ M. yessoensis populations in different parts of Pos'et Bay were found to be similar, and, correspondingly, so were the individual growth rates. In the sub-littoral zone of the open shores of Furugel'm Island the scallops were seen to grow somewhat/faster than in closed bays.

6. The environmental factors, listed in increasing importance, are as follows: seston content, phytoplankton pigment concentration, salinity, temperature, dissolved oxygen content. The last-named factor accounted for 88.5% variability in the growth rates of this year's brood of scallops.

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Description of figures

Fig.1. Diagram of the area of study.

Fig.2. An example of graphic illustration of the size-age structure of M. yessoensis populations. Troitsa cove, July-August, 1970. A - size structure, B - age structure. 1 - distribution of shell sizes in the sample, 2 - expected distribution within age groups, 3 - aggregate line (sum of normal curves). Figures within the curves show the number of specimens in the age groups.

Fig. 3. Comparison of rates of linear growth of M.yessoensis in closed bays and in the open part of the bay. 1, 2, 4, 5 - growth in Troitsa cove (data for other stations not shown because they are simmilar to the ones presented), 3 - growth in Zapadnaya cove on Furugel'm Island.
1 - growth of settled larvae (experimental observations), 2, 3 - modal lengths of shells, 4, 5 - adjusted growth curves: 4 - growth of sexually immature individuals; 5 - growth of sexually mature individuals.

Fig. 4. Correlation of absolute rate of growth of M.yessoensis (under conditions prevailing within the enclosure) to the time of year and water temperature in Troitsa cove
A - curve of changes of water temperature,
1 - 4 - absolute increments of different size-age groups.

Fig. 5. Phytoplankton pigment content in Pos'et Bay waters, 1972.

Fig. 6. Seston content in Pos'et Bay waters, 1972.

Fig. 7. Growth of this year's brood of Mizuhopecten yessoensis in suspended enclosures. Minonosok cove depth of 4.5 m. 1 - 5 - growth at planting densities of 80. 200, 400, 800 and 1600 specimens/m^2. Negative water temperatures are limited by arrows.